SMART CALL BOX FIELD OPERATIONAL TEST EVALUATION

SUMMARY REPORT

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ABSTRACT

Smart call boxes are an enhanced version of devices used as emergency call boxes in California. The overall system consists of a microprocessor, a cellular communications transceiver, solar power sources, data collection devices, maintenance computers, and data recording systems. The Smart Call Box Field Operational Test (FOT) evaluated the feasibility and cost-effectiveness of using smart call boxes for five data processing and transmission tasks: traffic census, incident detection, hazardous weather reporting, changeable message sign control, and video surveillance. Evaluation focused on cost-effectiveness, with effectiveness understood to include both functional adequacy and reliability and costs to include capital costs. telephone charges, and maintenancew costs. Due to schedule slippage it was impossible to evaluate reliability and maintenance costs. The smart call box concept was found to be feasible but not necessarily optimal. Functional systems for traffic census, hazardous weather reporting, and video surveillance were produced. Due to high wiring installation costs, these will often be cheaper to deploy than hardwire systems but are not necessarily superior to other wireless options. Significant system integration problems were-encountered. Systems produced by the FOT should be subjected to further testing and development to provide design enhancements, and to evaluate reliability and maintenance costs. Agencies considering deployment of smart call boxes; should. prepare detailed deployment plans to resolve such issues as ownership; financing and provision of maintenance services Institutional problems encountered in the FOT itself included inadequate involvement of the sponsoring agencies and potential users in system development, delays due to a lengthy vendor-selection process, and cumbersome contracting procedures; some of these might have been avoided by including of all major participants as partners in the FOT proposal.

Key words: intelligent transportation systems, field operational tests, call boxes, traffic data collection, wireless communications, institutional issues, cost-effectiveness.

EXECUTIVE SUMMARY

Smart call boxes are an enhanced version of devices used as emergency call boxes in California. The overall system consists of a microprocessor, a cellular transceiver, a solar power source, data collection devices, a maintenance computer, and data recording systems. The goal of the Smart Call Box Field Operational Test (FOT) was to demonstrate the feasibility and cost-effectiveness of using smart call boxes for five, data processing and transmission tasks: traffic census, incident detection. hazardous weather detection and reporting, changeable message sign (CMS) control, and CCTV surveillance. Test systems were designed and installed by two vendors, GTE Telecommunications Systems of Irvine.California and U. S. Commlink of San Leandro, California.

Evaluation of the FOT focused on assessing the cost-effectiveness of smart call boxes as compared with a baseline system using hardwire telephone communications. System effectiveness was understood to include both functional adequacy and reliability. Costs included capital costs, telephone charges, and maintenance costs. Due to schedule slippage. however, it was not possible to adequately evaluate reliability and maintenance costs, and the evaluation was primarily based on functional adequacy and capital costs.

Functional systems were produced for traffic census, hazardous weather reporting, and CCTV Surveillance. The CMS Control subtest was canceled prior to installation of equipment in the field. in part because it was discovered that the CMSs used in California are incompatible with smart call box systems. Incident detection systems were installed in the field but did not function correctly.

Important conclusions of the Smart Call Box FOT evaluation include the following:

1. The smart call box concept is feasible but not necessarily optimal. Due to the high cost of installing wiring, smart call box systems will be cheaper than hardware systems at many locations. On the other hand, they are not necessarily superior to other wireless options such as special-purpose systems consisting of sensors, cellular modems, and solar power supplies. One major motive for developing smart call box technology, was to create multipurpose devices that could take advantage of existing callbox infrastructure. The FOT demonstrated, however, that no more than two data related functions can be supported at a single call box without external power, even if existing solar power supplies are significantly enhanced. In addition, the systems produced by the FOT experienced significant system integration problems, some of which might have begn avoided by simpler systems. In particular, the call box microprocessors played little role in the systems produced by the FOT but may have contributed to.the system integration problems.

2. The major technical surprise encountered in the FOT was the difficulty of system integration. This was partly due to the difficulty of using devices (such as traffic counters and weather sensors) that had been designed for hardwire communication in wireless communication systems. It was also complicated by the presence of the call

box microprocessors, which added an extra communications interface, and by the presence of call box maintenance computers whose polling routines sometimes interfered with smart call box operation. Some of these difficulties could have been avoided had there been a standard communications protocol applicable to smart call boxes. Development of such a protocol as a part of the National Transportation Communications for ITS Protocol (NTCIP) is highly desirable. In order to produce standards specifically adapted to smart call boxes, the current NTCIP effort would need to be extended to include standards for smart call box higher level interactions. Actual development and adoption of such a protocol may depend on vendor perceptions concerning the potential size and profitability of the market for smart call boxes.

3. Systems developed by the FOT should be subjected to further testing and development prior to deployment. Goals of future testing and development should be to provide design enhancements. establish system reliability, and estimate maintenance costs.

4. In retrospect. a lack of quantitative market research was a major deficiency of the FOT. The potential size and profitability of the market for smart call boxes may be fairly limited. Prior to further development of smart call box systems, prospective vendors should conduct market research.

5 Agencies considering deployment of smart call boxes should prepare detailed deployment plans to resolve issues such as ownership, financing, and provision of maintenance services. Such planning should also include careful investigation of the qualifications of prospective vendors. Deployment plans are likely to differ significantly between California, where there is a well-developed system for installing and maintaining voice call boxes, and other states.

6. Important institutional features of this FOT included control by local agencies as opposed to the California Department of Transportation (Caltrans) Office of New Technology and Research, use of a private-sector project manager, and involvement of vendors through arms-length contracts. While these arrangements were effective for the most part, some of them contributed to problems encountered in the conduct of the FOT. Major institutional problems included inadequate involvement of both the sponsoring agencies and potential users in system development decisions, a lengthy and complicated vendor selection process, and cumbersome contracting procedures. Some of these problems might have been avoided by an organizational structure that included all major participants as partners in the original proposal.

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INTRODUCTION

Smart call boxes are devices similar to those used as emergency call boxes in California. They consist of a microprocessor, a cellular telephone transceiver, and a solar power source. The purpose of the Smart Call Box Field Operational Test (FOT) was to determine whether such devices are a cost-effective means of performing specified data processing and transmission tasks. The FOT was divided into five subtests, each focusing on a particular data processing/transmission task. The five subtests were as follows:

1. Traffic Census
2. Incident Detection
3. Hazardous Weather Detection and Reporting
4. Changeable Message Sign (CMS) Control
5. CCTV Surveillance

This report presents an overview of the FOT. Detailed descriptions of each subtest are presented in a separate report (I).

The FOT was motivated by a belief that smart call boxes could fill an important niche in the overall ITS architecture. At the time the FOT was proposed, the current draft of the proposed ITS architecture identified an entity called a “roadside terminal” that would be connected via bi-directional communications links to both transportation management centers (TMCs) and vehicles. It was felt that smart call boxes could serve this function.

In addition, the smart call box concept was particularly attractive in California because a well-developed voice call box system already exists. A second motivation for developing smart call boxes was to take advantage of the potential for multiple use of the existing call boxes. It was felt that the marginal cost of adding data processing and transmission features to existing call boxes would be less than deployment of special-purpose data terminals.

Beyond this, it was felt that smart call box technology possesses two important cost advantages. First. it avoids the need to provide electrical and telephone conduits to the roadside terminal. Since current California Department of Transportation (Caltrans) cost estimates for providing wiring amount to $ 11.00/ft for trenching, conduit, and wiring and $100/ft for jacking cables under the traveled way, elimination of wiring can result in a significant cost advantage at many sites. Second, the existing call boxes have been crash tested and approved for installation in the roadway clear zone. So long as smart call boxes do not significantly alter the weight distribution of the call box, their use avoids the tedious and expensive process of crash testing that might otherwise be required.

The goals of the FOT were to demonstrate the feasibility of using smart call boxes for the tasks outlined above, evaluate their potential cost-effectiveness, and identify institutional issues which might affect their deployment The FOT was successful in producing functional devices for three of the five subtests. It was less successful in evaluating their cost-effectiveness because schedule slippage compromised efforts to evaluate system reliability and determine maintenance costs. Finally, a number of critical institutional issues were identified some of which had substantial impact on the tests.

Participants

The Smart Call Box FOT was funded by the Federal Highway Administration (FHWA) and the State of California. It was carried out by a consortium (the FOT Partners) consisting of Caitrans District 11, the Border Division of the California Highway Patrol (CHP) and the San Diego Service Authority for Freeway Emergencies (SAFE)

Day-to-day management of the FOT was provided by a Project Manager. Initially, the Project Manager was the Titan Corporation; however, in March 1994 Titan sold this portion of its business to RMSL Traffic Systems, Inc. and RMSL acted thereafter as the Project Manager under subcontract uith Titan. On January 1, 1996 , RMSL changed its name to TeleTran Tek Services (T-Cubed); in this report this firm will be referred to as T-Cubed throughout.

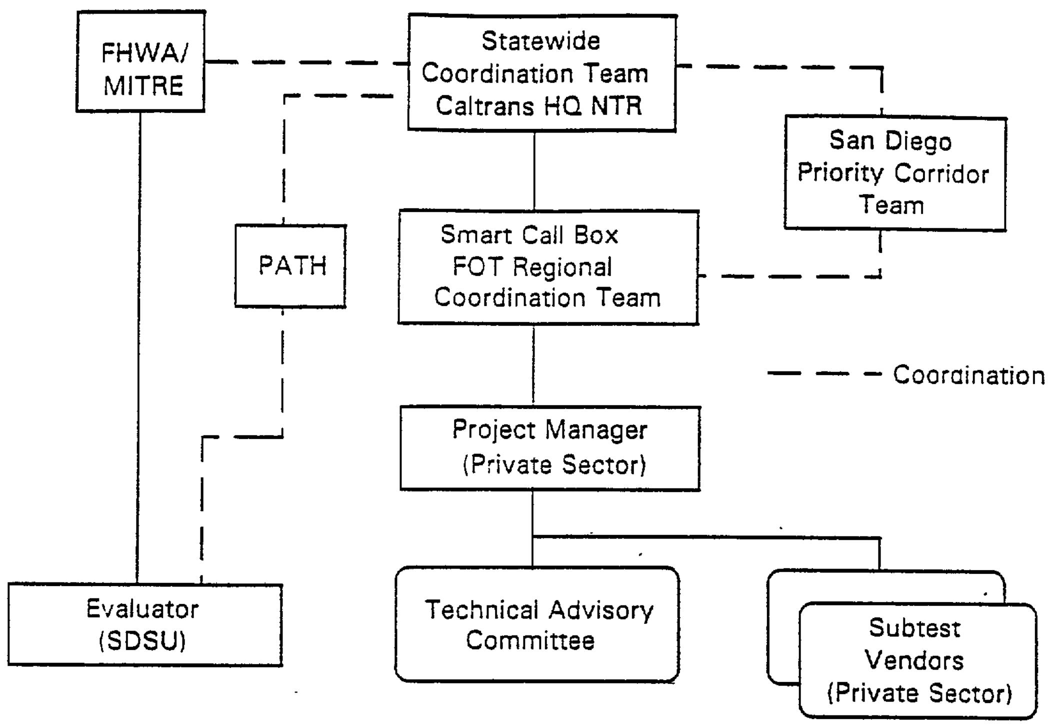
Independent evaluation of the FOT was provided by San Diego State University, under subcontract with the California Partners for Advanced Transit and Highways (PATH) program, which served as statewide Evaluator for California field operational tests.

Technical supervision of the FOT was the responsibility of a Regional Coordination Team (RCT) consisting of voting representatives of the Partners and non-voting representatives of the Project Manager and the Evaluator. In addition, non-voting representatives of FHWA the Caltrans Office of New Technology and Research, and PATH sometimes attended RCT meetings.

Design and installation of test systems was carried out by two vendor teams under contract with the Partners. One of these teams was led by GTE Telecommunications Systems of Irvine, California. The other was led by U. S. Commlink of San Leandro, California. A complete list of vendors included in the two teams is documented in an appendix. Input into the management of the FOT by the vendor teams (and, in theory, by any other interested individuals or firms) was provided by means of a Technical Advisory Committee (TAC).

Figure 1 is a schematic diagram showing the formal lines of authority and reporting among the participants in the Smart Call Box FOT.

Figure 1. Formal Lines of Reporting for the Smart Call Box FOT.



Goals and Objectives

Goals of the FOT evaluation were:

1. To evaluate the cost-effectiveness of smart call boxes.

2. To document and discuss the institutional issues encountered in the Field Operational Test.

Objectives related to the first of these goals were:

1.1 To determine (where feasible) the relative effectiveness of smart call boxes and a baseline system consisting of conventional telephone lines and Model 170 controllers for the tasks involved in the Field Operational Test, with effectiveness to include the functional adequacy, accuracy, and reliability of the data processing and data transmission provided.

1.2 To determine the projected life-cycle costs of smart call boxes and the baseline system.

1.3 To determine tradeoffs between smart call boxes and the baseline system in carrying out the tasks involved in the Field Operational Test and to determine which system is best for each task.

Objectives related to the second goal were:

2.1 To determine whether any institutional issues encountered in the Fieid Operational Test have a potential for affecting the performance of similar systems if widely deployed.

2.2 To determine the perceptions of participants in the Fieid Operational Test regarding the administration of the Field Operational Test, any other significant institutional issues encountered. and the effect of institutional issues on similar systems if widely deployed.

For purposes of the evaluation. the functional adequacy and reliability of the test systems were defined in terms of sets of performance standards, which were adopted by the RCT for each of the subtests. These were intended to reflect the needs of potential users of the test systems, as expressed by Caltrans District 11 traffic operations personnel. Ideally, performance standards would have been deveioped very early in the FOT and would have provided guidance for system design as well as evaluation. As it actually turned out, however, they were not issued until just before proposals were due from the vendors, and hence had little influence on basic system concepts, although they did influence some of the details of the designs. Also, in the course of the test, it was discovered that there had been omissions in the performance standards and that some of them were unrealistic or otherwise inappropriate.

Subtest Descriptions

The Smart Call Box FOT consisted of five subtests. For purposes of scheduling, these subtests were grouped into three subphases. As originally scheduled, Subphase 1 was to have included the Traffic Census and Hazardous Weather subtests , Subphase 2 was to have consisted of CCTV Surveillance subtest, and Subphase 3 was to have included the Incident Detection and CMS Control subtests. This proposed staging was based on the perceived difficulty of the system development tasks involved in each subtest. In September 1995. this phasing was altered to move the CCTV Surveillance subtest to Subphase 3 and the Incident Detection subtest to Subphase 2. This change was made because the FOT was lagging seriously behind schedule and was based on the relative amount of field data collection time expected to be required for these two subtests. Later, the CMS Control subtest was canceled because changes in the design of the test and technological advances independent of the FOT were judged to have undermined its usefulness, and the scopes of other subtests were altered because it appeared that vendors would not be abie to meet deadlines for installation of equipment. In addition, a "Subphase 0," a preliminary communications test, was scheduled to be conducted immediately after the initiation of the FOT. The five main subtests were as follows:

Subtest 1: Traffic Census

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for processing and transmitting traffic census data. Eight smart call box units were tested. These included a total of five different test system configurations developed by the two vendor teams. The team headed by GTE designed and installed two units. One of these employed a standard inductive loop traffic counter external to the call box and the other a loop counter mounted in the call box cabinet The other team, headed by U S. Commlink, designed and installed six units. Four of these employed standard inductive loop counters external to the call box. one employed an inductive loop counter mounted in the call box cabinet, and one employed an infrared detector counter. All traffic census installations except the U. S. Commlink infrared detector system used existing induction loops. All GTE installations involved modification of existing call boxes: but all U. S. Commiink call box units were specially installed.

Subtest 2: Incident Detection

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for processing and transmitting incident alarms In the course of planning for the subtest, it was decided to limit the test to detection of congested traffic as indicated by specified speed thresholds, rather than trying to distinguish between recurrent congestion and incident congestion.

Eight smart call box units were tested. These included a total of three different test system configurations developed by the two vendor teams. The team headed by GTE designed and installed six units, all of which employed inductive loop traffic counters mounted in the call box cabinet. The other vendor team, headed by U. S. Commlink, designed and installed two units. One of these employed a standard loop counter external to the call box and the other employed an infrared detector. All traffic census installations except the U. S. Commlink infrared detector system used existing induction loops. This complicated evaluation of the subtest,. because none of these loops were located in places were alternative sources of speed data were available (for instance, speed estimates from ramp meter volume and occupancy counts). All GTE installations involved modification of existing call boxes, but all U. S. Commlink call boxes were specially installed.

Subtest 3: Hazardous Weather Conditions Detection and Reporting

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for processing and transmitting hazardous weather alarms. Four smart call box units were tested. These included a total of three different test system configurations developed by the two vendor teams, The team headed by GTE designed and installed two units involving use of sensors to detect fog or other low visibility conditions. The other team, headed by U. S. Commlink, designed and installed two units. One of these was a low-visibility detection system sililar to that developed by GTE, The other consisted of a call box connected to a Davis Weather System, which was used to provide wind speed alarms. AlI weather sensors used in this subtest were specially installed ands were the U. S. Commlink cal1 boxes.GTE installations involved modification of existing call boxes.

Subtest 4: Changeable Message Sign Control

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for controlling changeable message signs (CMSs) It had been proposed to test four smart call box units. Due to problems encountered with system designs for this subtest and development of other technologies independent of the FOT, this subtest was canceled prior to the installation of equipment.

Subtest 5: CCTV Surveillance

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for controlling video cameras and transmitting video signals. Three smart call box units were tested. These included a total of two different test system configurations developed by the one of the vendor teams. The team led by U. S. Commlink provided three units. Two of these were monochrome fixed-field-of-view (FFOV) units and one was an FFOV color system that incorporated a pan-tilt-zoom (PTZ) camera (that is, the camera had PTZ capability but could not be controlled remotely). The vendor team led by GTE had also expected to participate in this subtest but was unable to meet the RCT's deadline for installation of equipment. All equipment used in this subtest was specially installed.

Tables I and 2 give configurations for all the test sites ultimately used. Figure 1 is a map showing their locations. It should be noted that the site numbering systems were developed by the vendors independently of one another, and are somewhat different. U. S. Commlink provided six sites, each of which was intended to be used for more than one subtest simultaneously; these were simply numbered consecutively, and numbers were retained when sites were relocated during the planning phase (as happened with Site 6). GTE, on the other hand, did not plan to conduct more than one test at a time at its sites, and actually numbered subtests, rather than sites. Consequently, in two cases, GTE sites were assigned two different numbers. These sites were designated as 2 and 3 for the Traffic Census subtest and 13 and 14 for the Incident Detection subtest. In addition, GTE did not retain site numbers when sites were relocated or subtests canceled; as a result, GTE site numbers are not consecutive. In Tables 1 and 2, the abbreviation "PM" stands for "post mile."

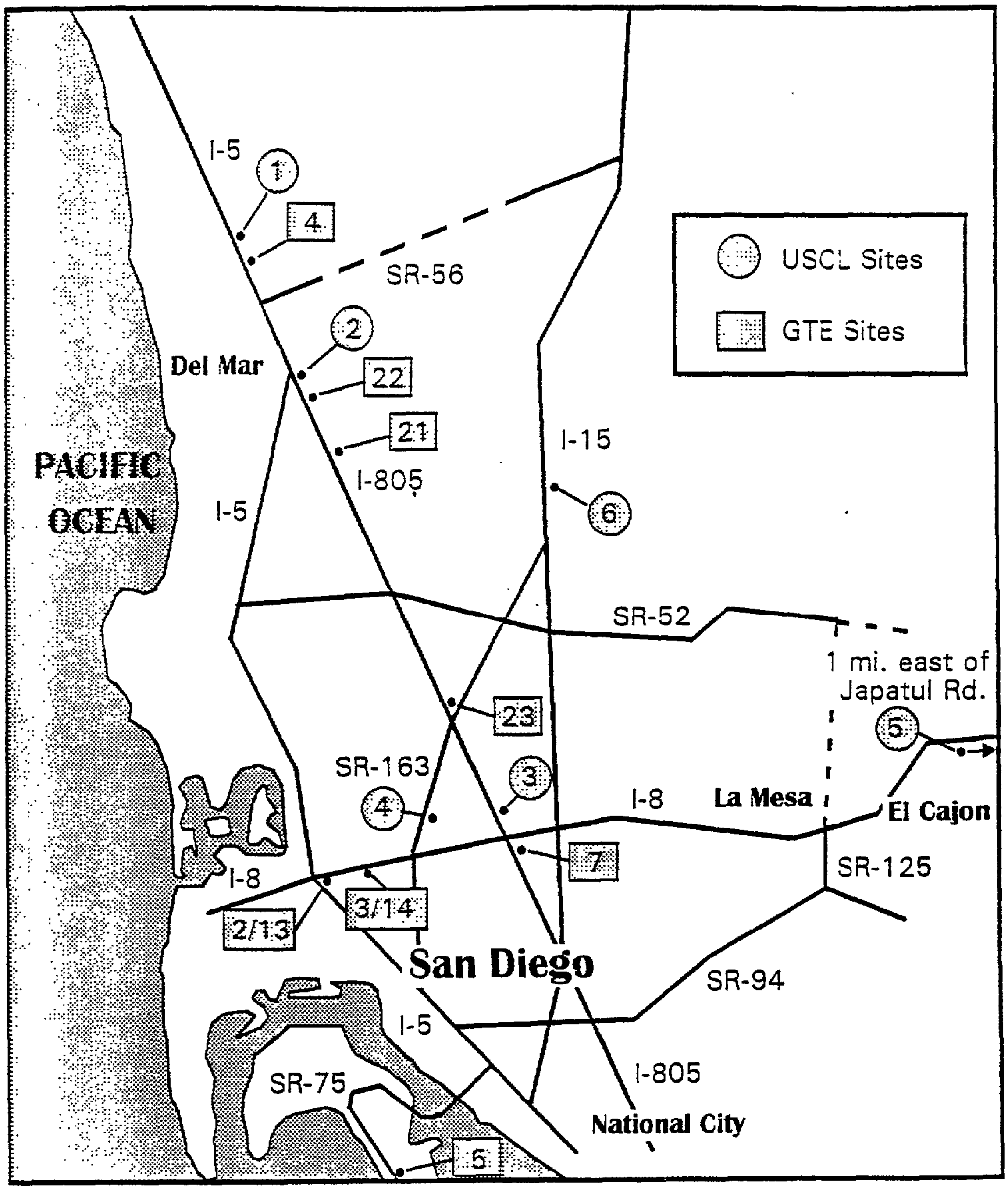
Table 1. Site Configurations for U. S. Commlink Test Sites.

Site No.	Site	Subject			
		Traf. Cen	Incid. Det	Weather	CCTV
1	I-5, PM NB 36.826	Ext. Det.	---	Jaycor	B/W
2	I-805, PM NB 28.526	Ext. Det	Ext. Det	---	Color
3	I-805, PM NB 18.296	Ext. Det	---	---	---
4	SR-163, PM NB 5.498	Ext. Det	---	---	B/W
5	I-8, PM EB 39.300	Int. Det	---	Davis	---
6	I-15, PM NB 12.957	Infrared	Infaed	---	---

Table 2. Site Configurations for GTE Test Sites.

Site No.	Site	Subtest		
		Traf. Cen.	Incid. Det.	Weather
2, 13	I-8, PM EB 0.214	Ext. Det.	Int. Det	---
3, 14	I-8, PM EB 1.450	Int. Det.	Int. Det	---
4	I-5, PM SB 35.200	---	---	Jaycor
5	SR-75, PM NB 17.600	---	---	Jaycor
7	I-805, PM NB 17.380	---	Int. Det	---
21	I-805, PM NB 25.300	---	Int. Det	---
22	I-805, PM NB 26.430	---	Int Det	---
23	I-805, PM NB 20.888	---	Int. Det.	---

Figure 2. Map Showing FOT Field Test Sites



TEST CHRONOLOGY

The history of the Smart Call Box FOT was marked by a great deal of schedule slippage. As will be clear from the narrative that follows, this had both institutional and technical causes. On the institutional side, there was the usual (or more than the usual) difficulty in getting contracts approved in a timely manner. In addition, the basic organizational concept of the FOT required an arms-length contractual relationship between the FOT Partners and the vendors. This resulted in a process that included issuing a request for participation (RFP), writing and evaluating proposals, and negotiating contracts. The amount of time required by this process was badly underestimated in the original planning for the FOT.

On the technical side, it was initially assumed that the smart call box systems would be assembled from off-the-she!f components and that. as a result, there would be minimal difficulty in designing them and working out initial design flaws. As it turned out: this approach resulted in major system integration problems, primarily involving communications software. When equipment installed as part of Subphase 1 of the FOT failed to work properly, the vendors concentrated their efforts on correcting the problems, and this delayed design and installation of systems in Subphases 2 and 3. The result was that, although functional systems were produced for all subtests except the CMS Control subtesr (which was canceled by the RCT) and the Incident Detection subtest (where none of the systems appears to have worked correctly); several systems were installed at the very end of the FOT and received minimal testing.

Organizational Phase – July 1992 - April 1994

The Smart Call Box FOT was proposed as a response to a request for proposals for IVHS field tests that was issued by **FHWA** on July 20, 1992. The proposal was submitted to FHWA on October 19, 1992. This proposal, although submitted on behalf of the FOT Partners. was actually written by employees of the Titan Corporation, the eventual Project Manager, in collaboration with the staff of the Caltrans Office of New Technology and Research. During the period in which-the proposal was under review, plans were going forward for several other field operational tests in California, and the California PATH program was selected as Statewide Evaluator for all of these. In late February 1993, PATH contacted SDSU about the possibility of serving as Evaluator for the Smart Call Box FOT, and SDSU responded with a brief "Draft Evaluation Plan" on March 10, 1993.

In late September 1993, FHWA approved funding for the project. Following this, the California Department of Transportation began processing an agreement with San Diego SAFE. serving as financial agent for the FOT Partners. In November, SDSU began to prepare a draft of a full-scale Evaluation Plan. even though no action had yet been taken to process the evaluation contract, which was separate from the FOT agreement. This draft Evaluation Plan went through several revisions and was eventually submitted to FHWA on an informal basis in mid-January 1994.

The agreement between the State of California and San Diego SAFE was finalized in late March 1994, with an effective date of April 3, 1994. Almost simultaneously, a contract was issued by San Diego SAFE on behalf of the Partners to Titan Corporation to serve as Project Manager. At about this time, however, Titan sold its IVHS Division to RMSL Traffic Systems. and subcontracted the project to RMSL. This led to concern on the part of the San Diego County Counsel that a conflict of interest might be involved. since both RMSL and U. S. Commlink, a prospective vendor for the FOT, were owned by Denbridge Electronics. By the end of May, this concern had been resolved with a finding that the relationship between RMSL and U. S Commlink was not close enough to constitute a conflict of interest.

Also, in April 1994, the Caltrans Office of Yew Technology and Research began processing of the evaluation contract. which had been held up pending the agreement between Caltrans and San Diego SAFE Due to a variety of problems, the interagency agreement between Caitrans and PATH was not completed until September 30, 1994 and SDSC did not receive its subcontract for the evaluation until November 1, 1994.

Vendor Selection -- May 1994 - June 1995

Despite the lack of an evaluation contract, the FOT went forward once the conflict of interest issue was resolved, with SDSU continuing to serve as Evaluator on an informal basis. The first tasks undertaken by the RCT and the Project Manager were to organize a preliminary communications test referred to as Subphase 0 and to prepare a request for participation by vendors. Meanwhile, in June 1994, SDSU began revising the draft Evaluation Plan in response to FHWA comments, and also produced drafts of Individual Test Plans.

According to the FOT proposal, the purpose of Subphase 0 was to “quickly demonstrate the concept of communicating sensor data from a call box to an evaluation site.” In addition. this test was expected to help identify some of the institutional issues that would be encountered in the main FOT. It was considered low-risk because similar systems were under development elsewhere in California and were expected to be operational by the time it was undertaken. Because it was perceived to be easy to accomplish. it was decided to pick the vendor for this subphase without a formal selection process. As originally scheduled, the vendor selected was supposed to be able to deliver the system within thirty days of notification to proceed, and the entire subphase, including site selection, vendor selection. and conduct of the test, was supposed to be accomplished in about six weeks. In fact, Subphase 0 was started in April 1994 and not completed until March 1, 1995.

There were a number of reasons for the delay. Proposals for Subphase 0 were solicited immediately after the start of the FOT in April 1994, and were received from both GTE and U.S. Commlink, the eventual prime vendors for the FOT. On June 1. 1994 the RCT selected the GTE proposal, based primarily on response time and cost considerations. GTE was informed of its selection in early July, but did not immediately proceed. In part this was because in the absence of a contract, GTE had been given no formal notice to proceed.

Once this issue was resolved, there were probiems resulting from GTE's failure to submit applications for encroachment permits. These permits are issued by Caltrans and are required in order for non-Caltrans personnel to perform work in the highway right-of-way. Encroachment permits are primarily intended to ensure the safety of workers and the traveling public but may also set forth conditions intended to prevent damage to state property or other unreasonable expense to Caltrans. For instance, the permits issued for the FOT were for temporary installation of equipment and contained clauses requiring the vendors to remove equipment and restore sites to their original condition upon completion of the test. GTE attempted to begin work without these permits and was reprimanded for the vioiation. Finally, in late October, a traffic counter was installed, but GTE did not connect it to the call box transceiver until December 1.

When it did so. however. the system failed to work. GTE eventually determined that there was a mismatch between the counter and the so&ware at the data collection site at the Project Manager's headquarters. On January 19, I995, GTE replaced the counter, but the system still did not work, and now the call box did not work either. On January 30, GTE replaced the controller card in the call box; this corrected the problem with the call box, but the counter still did not work. Finally, on January 31, GTE replaced the counter with one that had been proven in field use. At this point the system finally worked correctly, and data were transmitted to the Project Manager's offices. Data collection continued successfully through February 1995, except for some difficulties with the format in which the data were downloaded, and the test was finally terminated on March 1. As it turned out, the system integration problems experienced in Subphase 0 were to be typical of the entire FOT.

While Subphase 0 was underway, selection of vendors was proceeding. This process began with the release of a draft RFP at a meeting with prospective vendors on July 27, 1994; a final RFP incorporating changes based on comments received at this meeting was issued on August 18. This was amended on two occasions prior to the deadline for submission of proposals in October 1994. The second of these two addenda, which was issued about a week before the deadline for proposal submission, outlined the proposed data flow for the various subtests and introduced a set of performance standards describing the desired finctioning of the test systems.

The introduction of performance standards at a point this late in the proposal process was a result of the fact that Project Manager had proceeded independently of the Evaluator in writing the original RFP on behalf of the RCT. The concept of performance standards had arisen in the course of preparing the draft Evaluation Plan; these standards were seen as being the basis for measures of effectiveness for the various test systems. From the Evaluator's point of view, Caltrans District 11 operations personnel, as the "customers" for the test systems, were the logical source of performance standards; however, Caltrans had taken no action to develop any, and the RFP was issued with rather loose descriptions of the desired technicl features of the test systems. Finally, in August, the Evaluator arranged a meeting with Caltrans operations personnel to discuss the issue. One key individual could not attend due to illness, so a meeting with this individual was held in early October 1994. Based on input at these meetings, the Evaluator proposed performance standards that were revised and adopted by the RCT at its October meeting.

Proposals were submitted by two vendor teams, one headed by GTE and the other by U. S. Commlink. Initial proposals were received on October 24, 1994. Following review and comments by the RCT and Project Manager, revised proposals were submitted on November 22, 1994. There followed a series of negotiations with the vendors concerning the scope of the FOT and details of the proposals. These negotiations included face-to-face meetings on December 21, 1994 and correspondence during the months of January and February 1995.

On January 23, 1995, a working group of the RCT met to recommend cuts in proposed test activities in order to bring them into line with the FOT budget. The results of this meeting were reviewed by the full RCT on February 1 and final decisions made as to the scope of each subtest. Throughout the proposal review process, the RCT had discussed the possibility of partially funding both proposals. One motive was to provide backup in case one vendor was unable to perform; also, there were features in both proposals that interested the RCT. The final decision was to fund both vendors for all subtests, but for reduced numbers of units in each test This decision-had a negative effect on subsequent progress by the vendors as from the vendors' point of view it divided the funding in half without reducing the total engineering effort required.

After the RCT' s decisions at the beginning of February 1995 and submission of responses by the vendors in mid-February, the RCT and the vendors entered into contract negotiations. A contract with U. S. Commlink was executed on April 6. Contract negotiations between the RCT and GTE were somewhat more protracted. GTE's legal counsel objected to a number of clauses in the original draft of the contract, and these issues were not resolved until June. The GTE contract was finally executed on June 26, 1995.

While the vendors were preparing their proposals, SDSU was continuing to work on the evaluation documents. In August, SDSU responded to FHWA and Mitre Corp. comments on the draft Evaluation Plan and Individual Test Plans. Following further revision of these documents in October, and receipt of the evaluation contract, the initial versions were issued officially on November 21, 1994. Later, in January 1995, SDSU prepared a Data Management Plan.

Initial Field Installations -- July 1995 - December 1995

Once the contracts were in place, the vendors proceeded with selection of specific test sites and design of the Subphase 1 test systems (for the Traffic Census and Hazardous Weather subtests).

GTE had proposed specific sites as eariy as its revised proposal of November 22, 1994: but these had never been confirmed by the RCT. Following the changes in scope at the beginning of February 1995, a second list was submitted, but once again, no action was taken to confirm the sites. U. S. Commlink, on the other hand, had only developed a set of "site descriptions" detailing site requirements and equipment to be installed at each site; this had been presented at a TAC meering on May 10. Following two meetings with Caltrans personnel U. S. Commlink designated specific sites, which were presented to the RCT on June 7. On June 28 1995, following execution of its contract, GTE distributed revised site configurations. A meeting between Caltrans and GTE to review the sites was held on July 5, GTE received Caltrans' input at this meeting but did not issue the final list of sites until early September.

The timing of the installation of equipment for Subphase 1 was dependent on the vendors' progress in designing the test systems. This, in turn, was affected by their basic design approaches, which were rather different. U. S Commlink proposed to establish a limited number of multipurpose sites. In its original proposal, half of these were to be in the San Francisco Bay area. near its headquarters; however, the RCT vetoed this on the grounds that activities outside the San Diego area were beyond the scope of the FOT . GTE, on the other hand, proposed a large number of single-purpose sites. In February 1995, it had appeared to reverse this decision, but returned to it when it proposed its tentative list of sites at the end of June 1995. U. S. Commlink seriously pursued approaches that would allow call boxes to be continuously accessed at any time from the data collection center. GTE, on the other hand, did not propose to provide continuous access, except where it was absolutely necessary, relying instead on the use of predetermined time windows for downloading data. Finally, GTE proposed to design ail systems to operate on solar power only, but U. S. Commlink designed systems requiring A/C power for all but one of its test sites.

As a result of these differences in design approaches, GTE was able to install equipment sooner than U. S. Commlink. GTE began installation of equipment for Subphase 1 in early September 1995. Equipment was installed at two sites for each subtest. In the case of one of the traffic census sites, however, there was a delay in hooking up the existing loop detectors, which was not resolved until February 1, 1996.

In May 1995, field installation of the U. S. Commlink systems had been projected to take place as early as mid-June. As more detailed design proceeded, however, U. S. Commlink decided to redesign its microprocessor card and carry out extensive laboratory testing, and this delayed deployment of field equipment until the beginning of November.

In addition to the field units installed by the vendors, data collection equipment located at the Project Manager's headquarters was required. Installation of this equipment was the responsibility of the Project Manager. Two suites of communications and computer equipment were installed. The first, which was installed in September 1995: was intended to interface with GTE's field equipment. The other, which interfaced with U. S Commlink's equipment. was installed in October 1995.

As the projected installation dates for Subphase 1 equipment continued to slip, the RCT became concerned about the potential effect of this schedule slippage on the evaluation of the FOT. In August, the RCT issued a new schedule which moved the Incident Detection Subtest to Subphase 2. with equipment installation scheduled for December 1, and the CCTV Surveillance to Subphase 3, with equipment installation scheduled for March 1, 1996. The CMS Control Subtest remained in Subphase 3. The motivation for switching the phasing of the Incident Detection and CCTV subtest was that the evaluation of the Incident Detection subtest was expected to require more data collection.

Once it was installed in September 1995, the GTE traffic census site did not function correctly. Failures included a number of problems reiated to either equipment malfunctions or system integration problems which were resolved during October and November However, GTE had still not succeeded in transmitting traffic census data to the data collection point by the beginning of January 1996. GTE's weather sites, which were limited to detection of low visibility, were more successful initially. Although they also suffered from problems with equipment malfunction and system integration. they xvere able to transmit numerous fog alarms beginning during the month of November 1995, which turned out to be exceptionally foggy.

U. S. Commlink began equipment installation for its sites at the beginning of November 1995. Since all six U. S. Commlink sites were involved in the Traffic Census subtest, all were involved in the initial installation effort, although equipment needed for the other subphases was added later.

U. S. Commlink traffic census sites included three different types of traffic counting schemes: most were loop detectors with external counters, but there was one site that employed Ioop detectors connected to a counter mounted in the call box cabinet, and one that employed an infrared detector. Initial installation and system integration appeared to be successful at sites using loop detectors, although there were numerous software problems, some of which caused field units to erase data every time they were contacted. This did not prevent downloading of current data, however, and data were successfully transmitted to the data collection point by mid-December. U. S. Commlink had problems in keeping the loop detector sites operational, however: although all but one site had functioned successfully at some time before the end of the year, only two sites were actually fictioning as of December 31, 1995.

The infrared detector, on the other hand, did not function correctly upon installation. The infrared beams were ranging no more than 4 - 5 feet from the detector, which was mounted on an overhead sign. This meant that only large trucks could be detected. The manufacturer of the infrared detector was reported to suspect a power supply problem, but the problem actually turned out to involve a bad ground wire.

Initial installation and integration of weather reporting equipment by U. S. Commlink was even less successful. U. S. Commlink had proposed to provide two different types of weather station: a Davis weather station, to be installed at its Site 5, located in the mountains east of San Diego; and a Vaisala weather station to be installed at its Site 1, located near the coast. The Davis weather station was installed in early November, but was subsequently damaged when its anemometer was accidentally broken off the pole. By the beginning of January, the Davis station was still not repaired, and no weather alarms had been transmitted Meanwhile, no action had been taken to install the Vaisala station.

Thus, by the end of December 1995. the only systems that were functional were the GTE visibility sites and the U. S. Commlink loop-detector traffic census sites -- and these latter were still clearly unreliable. Meanwhile, the vendors had been so concerned with getting their existing installations to work that little progress had been made on designs for Subphases 1 and 3 Borh vendors had missed the December 1 deadline for installation of Incident Detection systems. and there was little evidence of progress on either of the Subphase 3 systems.

Facing Reality -- January1996-February1996

By early January 1996, the RCT was once again concerned that the FOT might not be completed on schedule. Particular concerns included the failure of the GTE traffic census units to provide successful transmissions to the data collection point, the failure of U. S. Commlink's infrared sensor unit to function properly, and lack of progress by U. S. Commiink in getting its weather stations operational. At its January 4 meeting, the RCT refused to fully fund vouchers that GTE had submitted, on the grounds that the traffic census units were not completely operational, and voted to have San Diego SAFE send both vendors notices to cure default.

The notices were distributed at the January 11 TAC meeting, along with a schedule revision establishing "firm" dates by which data collection was to begin for each subtest. In the case of the Subphase 1 subtests that were not yet operational, the deadline was January 26. The Deadline for Subphase 2 was to be February 15. The deadline for Subphase 3 remained March 15.

By the time the notices were distributed. GTE had managed to demonstrate successful functioning of the traffic census unit at its Site 1, although this site was not consistently operational until the near the end of January. U. S. Cornmlink, on the other hand, informed the Project Manager on January 26 that it would not be able to meet the deadlines for its weather stations or for the incident detection subtest. U. S. Commlink proposed that the deadlines for the weather stations be delayed until April 12 for the Davis system and April 19 for rhe Vaisala installation and that the deadline for the Incident Detection Subtest be delayed until May 3. On the other hand, U. S. Commiink stated that it could install the FFOV portion of the CCTV equipment ahead of schedule (by February 16), but that PTZ equipment would not be ready by that date.

The RCT was unwilling to allow this much delay for the Hazardous Weather Reporting subtest. since high wind and low visibility conditions would be unlikely to occur as late as April Also, the U S. Commlink's proposai to delay installation of the Incident Detection equipment until May 3 was considered unacceptable, since it left little time for data gathering to verify functioning of the system. The Project Manager was authorized to negotiate with both vendors to determine whether various portions of the FOT should be terminated or rescheduled. As a result of these negotiations, the RCT agreed to a compromise in which the Vaisala station was to be dropped from the test, an additional Davis weather station and a Jaycor visibility device were to be added at Site 1, and both systems were to be operational by February 15. Also, U. S. Commlink was to simplify its design for the Incident Detection units and have them operational by February 29. The deadline for the CMS Control and CCTV Surveillance Subtests were to remain March 15.

Meanwhile Caltrans had been evolving a policy for CMS control for the CMS Control Subtest. As originally envisioned, the CMSs were to be controlled from the Caltrans TMC. By August 1995. however, this idea had been dropped in favor of having all FOT functions controlled from the data collection point at T-Cubed headquarters. This led to discussions as to how the TMC could preempt signs during the test if this proved necessary. Discussions within the Caltrans District 11 staff and between Caltrans, the Project Manager. and the vendors took place over the course of several months. Draft procedures were finally issued by Caltrans at the January 11, 1996 TAC meeting.

U. S. Commlink had begun serious efforts to design a CMS control system, even though it was still having problems with the reliability of its traffic census sites and had failed to get the Davis weather station unit back in operation. By the end of February it was apparent that the March 15 deadline for equipment installation for the CMS test would not be met and that the vendors probably would not be able to meet some of the other deadlines that had been set in January, At about the same time it became apparent that, as a result of the continuing series of problems, time spent on the FOT by the Project Manager had greatly exceeded that budgeted and would result in serious cost overruns if allowed to continue at its present rate. With this in mind, the Project Manager reviewed the remaining FOT tasks to identify those that had the greatest probability of success. This review resulted in a recommendation that the CMS Control Subtest be terminated, and this recommendation was approved by the RCT on March I.

Reasons for the termination of the CMS Control subtest included changes in the concept of the test itself, system design problems, and technological developments that were independent of the FOT.. Together, these were judged to have undermined its usefulness. As originally envisioned, the CMS subtest had been intended to test communications between one call box equipped with sensors and another controlling a CMS. It had been assumed that automatically-posted CMS messages (in response to a hazardous weather alarm, for instance) would be acceptable and that the CMS could be controlled from a call box. It turned out. however. that the Caltrans TMC was unwilling to use automatically-posted messages. In addition, research into the tinctioning of the CMS signs used in California revealed that their operation was incompatible with control by a smart call box.

This meant that the call box could only serve as a communications link. Meanwhile, however, Caltrans had independently acquired the ability to use cellular telephone links with the CMS. controllers. Consequently, there did not seem to be much value in continuing the test.

Subphase 2 -- March 1996 - April 1996

By the end of February both vendors were working on designs for their CCTV systems. and were preparing to install their incident derection units. In the case of GTE this involved replacing the counters used at the two traffic census sites, and establishing four new sites. In February: shortly before these were installed, several of the proposed locations for this test were changed. U S. Commlink, on the other hand, expected to be able to adapt two of itstraffic census counters to send congestion alarms. These were the external-counter loop-detector unit at its Site 2 and the infrared unit at its Site 6. In both cases, the actual software modifications were the responsibility of the counter manufacturer. In the case of site 3, however. Peek Traffic Systems was unable to get the ADR-3000 counter used in the Traffic Census subtest to send alarms, so an older mode1 Peek device (a Peek SOH Counter), which was na longer in production, was substituted.

The two GTE traffic census sites were converted to incident detection around the beginning of March. At about the same time. U. S. Commlink installed the low-visibility detection system at its Site 1, reinstalled the Davis weather station at its Site 5 (although it was not functional until some time in April), and managed to reactivate two traffic census sites that had been down with power supply problems. The second Davis weather station, which was supposed to be at U. S. Commlink Site 1, was never installed, however.

The GTE incident detection systems never functioned correctly, and only one alarm was ever transmitted to the data collection center. Meanwhile, these units were also supposed to be available for downloading of data during predetermined time windows. but they became inaccessible because the GTE maintenance computer reset the time windows unpredictably. Neither of these problems was resolved before the end of the FOT.

The U. S. Commlink low-visibility system also never transmitted a “real” alarm, although alarms were artificially induced. This was presumably due to the fact that the site was no longer experiencing fog by Much. By mid-April, the Davis weather station unit was operational, but no alarms were being received at the current windspeed threshold of 30 MPH. This was corrected by lowering the threshold to 20 MPH, and thereafter numerous alarms were transmitted. Also in mid-April U. S. Commlink was able to get the infrared detector traffic census unit back in operation. but there were still problems with the accuracy of some of the data. This unit was shut down near the end of the month so that the detector manufacturer could install a firmware upgrade, and was not back in operation until nearly the end of May.

Final Phase – May 1996 - June 1996

Funding for the FOT was scheduled to expire June 30, 1996. The RCT arranged for an extension of its authorization to spend, but did not extend the expiration dates on the vendor contracts (also June 30), and scheduled May 15 as the end of data collection. It was decided that since the functionality of the CCTV systems could be demonstrated quickly. installation as late as May 9 (the scheduled date of a TAC meeting) would be accepted. U. S. Commlink succeeded in installing its CCTV systems around the beginning of May: GTE, on the other hand, was unable to install its CCTV system by May 9, and this portion of the CCTV subtest was canceled by the RCT.

U. S. Csmmlink also got its incident detecrion systems to send alarms to the data collection center around the first of May. The infrared unit at Site 6 was still down for installation of a software upgrade, and did not send alarms based on real traffic data until the end of May, but Site 3 sent numerous alarms starting the first week in May. The validity of these alarms was questionable, however, since the times and durations of the congestion incidents they indicated were not as expected. By using the CCTV installation at U. S Commlink Site 2, it was eventually possible to confirm that alarms were not always being sent when congestion was present.

An initial test at one of the U. S. Commlink monochrome CCTV sites, which was intended to verify CMS messages, was held May 7. In this test, image quality was poor, but it was possible to read the CMS On May 14, a demonstration invoking all three sites was held for representatives of the District 11 TMC, but once again there were problems with image quality.

Since the U. S. Commlink incident detection and CCTV sites were newly functional, it was decided to extend data collection as long as possible; data used in the evaluation were collected as late as June 13, and the CCTV unit at U. S. Commlink Site 2 was used in mid-July to confirm problems with the incident detection system at this site. On May 23, all three CCTV systems were adjusted to improve image quality. On May 29, the Project Manager had planned to conduct a night test to determine whether the system was capable of producing readable images of the CMS under low light conditions. Before the test could be conducted, however, both monochrome systems failed. An attempt was made to correct these malfunctions on May 30, but it was unsuccessful, and neither site was operable at the end of data gathering on June 13. Also, on June 10, it was discovered that two of the visibility paddles at Site 1 had been hit by a vehicle and knocked down.

U. S. Commlink Site 6 was reactivated with new firmware near the end of May, and following this both U. S. Commlink incident detection sites produced alarms on a regular basis, although their validity continued to be questionable.

During this time period, a major part of the data analysis for the evaluation was performed. As a part of the analysis of institutional issues, FOT participants were interviewed to determine their perceptions about the administration of the FOT, the possible effect of institutional issues on the outcome of the FOT itself, and potential institutional barriers to the implementation of smart call box systems. Although some of these interviews were conducted as early as mid-April, most took place around the end of May and the beginning of June. Also, during June, traffic data and incident alarm logs were analyzed to evaluate the accuracy of the traffic census and incident detection systems. Initial drafts of the summary report and the various subtest reports were issued. on July 3.

Follow-Up Activities

As the completion of the FOT approached, there were discussions of possible follow-up activities, including the potential deployment of some of the systems involved in the FOT. In the San Diego area, this resulted in a decision to prepare a proposal for pilot deployment of selected smart call box systems as a part of the Southern California Priority Corridor Showcase Project. This proposal calls for small-scale deployment of smart call box systems for traffic census. low-visibility detection. wind-speed monitoring, and verification of CMS messages by CCTV. The proposed piiot deployment is intended to provide for further testing and system development (as recommended elsewhere in this evaluation report) and to increase confidence in eventual decisions to deploy (or not deploy) full-scale systems. The pilot deployment proposal calls for integration of all proposed systems into the District 1 I TMC; in the cases of the low-visibility and wind-speed alarm systems, this also involves developing or installing display systems at the TMC. In addition, the proposal for pilot deployment of the low-visibility system calls for establishment of a network of sensors in an area with a high incidence of visibility-related accidents. At the time of this writing, it is not known whether this proposal will be funded or not.

Elsewhere in California, smart call projects are currently underway in the San Bernardino-Riverside area, and in Sutter County. The San Bernardino-Riverside project was actually underway before the Smart Call Box FOT, and involves traffic census and weather warning systems. The Sutter County project, which has just recently begun, involves traffic census and low-visibility detection systems. In addition, planning is underway for smart call box projects in the Los Angeles County-Ventura County area, and in the San Francisco Bay Area.

In addition to activities related to further testing or potential deployment, the RCT sponsored a workshop on July 17 that was attended by about fifty persons from public agencies and private firms. The goal of this workshop was to publicize the results of the FOT.

TECHNICAL RESULTS

The Smart Call Box FOT involved the design and testing of smart call box systems to carry out various data processing and transmission functions. The technical results of the FOT include both the design and functioning of these systems. The section on System

Design that follows summarizes the vendors' approaches to the key design issues involved, and evaluates the extent to which design problems were solved. The section on system Performance evaluates the extent to which test systems performed as designed. It is followed by a discussion of the most significant of the technical issues and their impact on the viability of the smart call box concept.

Evaluarion of system design and performance was based on measures of effectiveness derived from a set of performance standards adopted by the RCT. These performance standards, in turn. were based on input from Caltrans operational personnel and were intended to ensure that test systems would meet their needs and be compatible with existing TMC equipment and procedures.

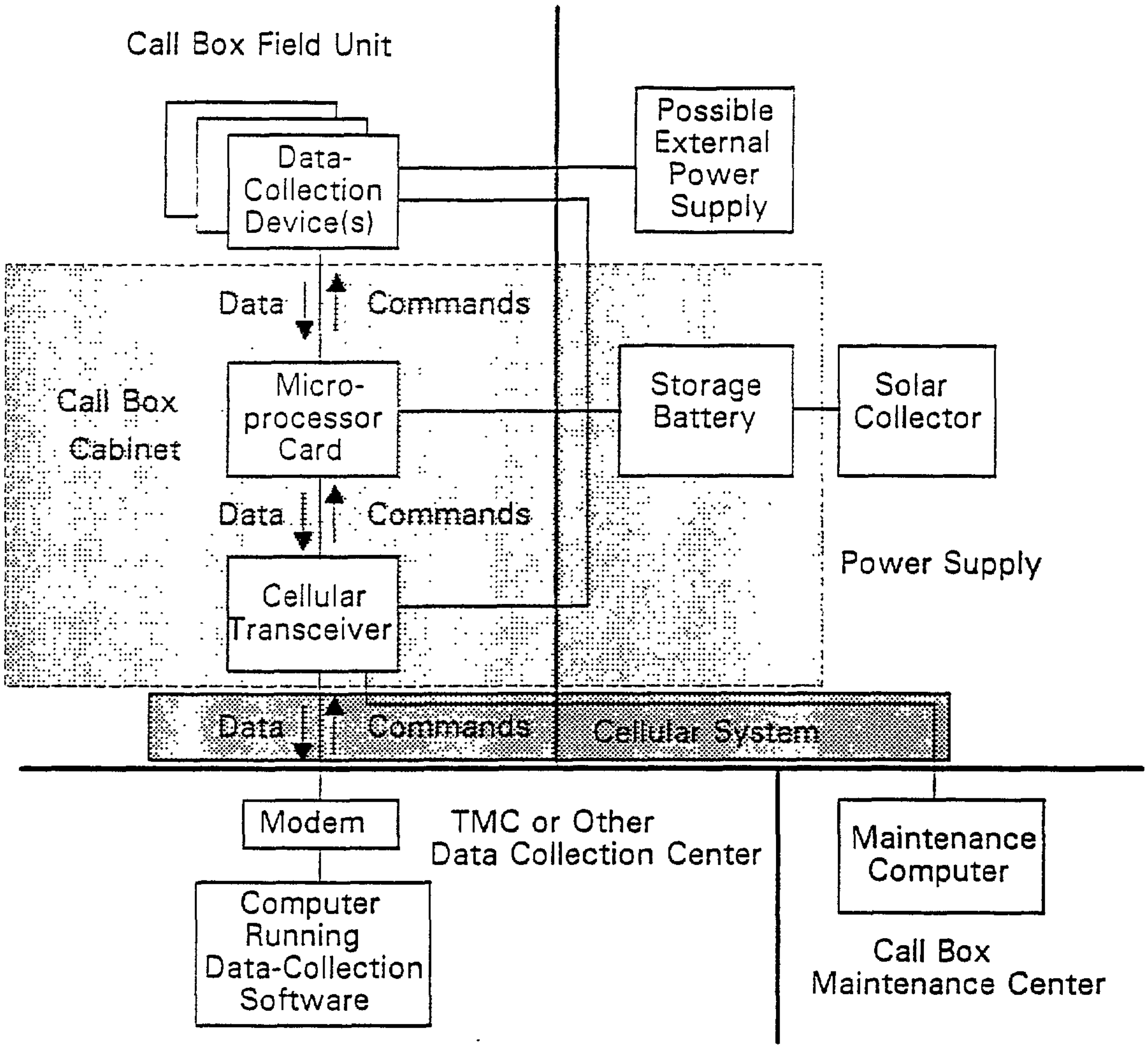
For the most part these performance standards provided a reasonable basis for design and evaluation of the test systems; however. in some cases they were probably too restrictive and in other cases turned out to be unrealistic Finally. in several cases, they simply overlooked issues that later turned out to be of practical significance. This was particularly true of descriptions of alarm procedures for the Incident Detection and Hazardous Weather Reporting subtests. These assumed (but did not actually state) that vendors would design devices to provide notification every time a threshold was crossed either to or from an alarm condition and that alarms would be transmitted in a form that could be automatically recorded in a computer file or otherwise manipulated. In fact, the systems actually designed only provided FAX transmissions and did not always provide "all clear" signals.

In retrospect, the performance standards would probably have provided a better basis for evaluation had a wider range of people been involved in their development. In particular, participation by representatives of the vendors, the sponsoring agencies, and operational personnel from outside Caltrans District 11 would have been useful. Also, their effectiveness as an evaluation tool would have been enhanced by better communication with the vendors during the development of the test systems, so that unrealistic or inadequate standards could have been identified and revised.

System Designs

The basic concept of a smart call box is that it is a multipurpose data processing and transmission system involving an independent solar power supply and wireless communications. Figure 3 is a block diagram showing the architecture of a generic smart call box. The key features of the ideal smart call box system include: 1) it should serve multiple functions. to include voice transmission and possibly several types of data transmission and 2) it should be able to function without an external power supply. In addition, several of the tasks included in this FOT also required that the TMC be able to access the field unit at any time. Key design issues resulting from these requirements include:

Figure 3. Generic Smart Call Box System Architecture.



- *System architecture*. A major issue is that of which data processing tasks are to be performed by which components. One of the assumed advantages of smart call boxes is that call box microprocessors possess surplus computing capacity that can be exploited for other purposes. This was emphasized in some of the early literature produced by proponents of the FOT, which refers to the call boxes as "computers on a stick." On the other hand, existing counters and weather sensors already have considerable data processing capability. The issues here are whether the call box microprocessors really have significant additional capacity and whether, if they do, there is any need for it.

- ***Sytem integration.*** Smart call box systems consist of a number of components which were not originally designed to work together. How to get these compcnents to work together is a major system design issue. In particular, integration of systems of this type is apt to involve numerous software, hardware, and system compatibility problems.

- ***Power supply.*** A critical feature of all smart call box system designs is how to provide the necessary data processing and transmission functions with the limited power supply provided by solar collectors and storage batteries. The need for continuous accessibility increases the demand for power, as does the need to power multiple auxiliary devices such as sensors or video cameras. Power supply is thus a major limitation on the potential complexity and effectiveness of smart call box systems. Potential solutions are to design components and system operation to minimize power consumption, increase solar power supplies. or compromise the objective of independent power supply by designing systems that require external A C power.

- ***Physical connectivity.*** If smart call boxes are serve as multipurpose devices, it is necessary to be able to connect the various components. This requires that call box microprocessor cards be designed to accommodate multiple ports. It also'poses a problem of designing connections in such a way that all the necessary wiring can be accommodated in the confined space provided by the call box cabinets, which are much smaller than those used for signal controllers and similar devices.

- ***Sequencing of transmissions.*** In the case of multipurpose smart call box systems, situations can arise in which there are conflicting demands for use of the cellular transceiver. Potential conflicts include those between voice and data transmissions, between different types of data transmissions, and between control commands being sent to the field unit and data being downloaded from it. Besides the potential conflict between voice and data communication, the most obvious such conflict is that between video signals and control signals for PTZ video systems.

- ***Integration with the TMC*** A final design issue relates to the integration of data from smart call boxes into the data systems and operational routines of TMCs. The complete system has to be integrated all the way from the sensor or other field device to the ultimate user. This involves consideration of how data are to be displayed and used, so that data can be provided in a useful form.

Test system designs for the Smart Call Box FOT approached these key design issues as follows: .

System Architecture

With one exception, neither vendor produced system designs in which key data processing functions were carried out by the call box microprocessor. Rather, both took maximum advantage of the data processing capabilities of the weather sensors and traffic counters.

This appears to have been a result of both the limited additional computing power of the call box microprocessors and the inefficiency of having to write software for functions the sensors could already do. In only one case was a call box microprocessor used for a function involving more than minimal logic. U. S.Commlink's external counter incident detection system did use the call box card to prompt data bursts from the Peek SOH counter and to evaluate current speed to determine whether a threshold had been crossed. Otherwise, the only essential tasks performed by the call box microprocessors, other than those reiated to the call boxes themselves, appear to have been sending the FAX messages used in the alarm systems.

Otherwise, the two vendor teams followed somewhat different approaches to system architecture. For instance. GTE did not attempt to design multipurpose smart call boxes. That is, each GTE system was designed to provide voice communications and one additional function such as traffic census or hazardous weather alarms. U. S Commlink, on the other hand, redesigned its call box microprocessor card to be able to provide four ports for external devices. such as weather sensors, traffic counters, or video compression units. All U. S. Commlink sites were originally intended to test multipurpose systems, and all but one actually did so.

System Integration

All test system designs involved integration of external field devices such as traffic counters, weather sensors, or video compression units with the call box microprocessors and the microprocessors, in turn, with equipment and/or software at the data collection center. The simplest design was that for the alarm systems, in which the call box relayed a FAX message to the data collection point. Those for the traffic census and CCTV systems also involved integration with software running on computers at the data collection center. System integration failures were a major problem in the performance of the test systems,

Power Supply

The two vendor teams took a somewhat dufferent approach to dealing with power supply constraints. GTE placed major emphasis on providing systems with independent power supplies, but (partly because of the power constraints) was unable to provide either multipurpose systems or continuous accessibility. GTE did propose to provide continuous accessibility by keeping the call boxes on very low-power standby and using a commercial page service to transmit a signal to cause them to power up to receive incoming calls. Such capability was absolutely required by the CCTV Surveillance and CMS Control subtests, but GTE never installed any equipment for either of these. The CMS Control subtest was canceled at the option of the RCT, and GTE missed the deadline for equipment installation for the CCTV Surveillance subtest.

U. S. Commlink, on the other hand, took the approach of redesigning its call box card to reduce power consumption and by this means was able to provide both continuous receive mode capability and limited multipurpose capability with a somewhat augmented solar power supply. U. S. Commlink was able to operate both traffic census and hazardous weather alarm systems at its Site 5 without external power, but was not able to provide for downloading of weather data over the entire 24 hour period each day. U. S. Commlink expects to be able to provide 24-hour capability for both these functions at a single site by further reductions in the power requirements of its components. Otherwise, U. S. Commlink did not place a great deal of emphasis on the goal of providing independent power supplies, concentrating instead on providing more sophisticated sensors, multiple-function sites, and continuous receive-mode capability. As a result, five of the six U. S. Commlink sites did require external power.

Physical Connectivity

As previously mentioned. GTE did not pursue designs that would provide for more than one external device at a time to be connected to a call box. U. S. Commlink was able to provide ports for up to four additional devices.

Sequencing of Transmissions

All system designs provided for priority of voice transmissions over data transmissions, although this feature was never actually tested in the FOT. Neither vendor was able to solve the probiem of providing for remote control of a PTZ camera.

Integration with the TMC

Design of portions of the system to be located at the TMC was considered to be outside the scope of the FOT. As a result, system designs either employed existing data collection components or employed the simplest possible means. In the case of the Traffic Census and CCTV Surveillance subtests, existing data collection software developed for particular counters or video compression systems was used. In the case of the alarm systems, FAX transmissions were used because they were simple and resulted in a permanent record of the transmission. One result is that the alarm systems are of little immediate usefulness, because there is no way of recording the alarms in electronic form or entering them into an alarm display system.

In addition to these major design features, test system designs involved a number of details related to their intended tasks. Specifications for these were set forth by the performance standards and the RFP. For the most part, these standards were met.

One exception was the infrared-sensor system designed for the Traffic Census subtest. The memory and time-keeping system of this counter are inadequate for normal traffic census use. In addition, this system is limited to one lane per counter, so that no more than four lanes can be counted from a single call box, given U. S. Commlink's current call box design.

Also, although the weather alarm systems met the performance standards, but in this case the standards themselves may have been inadequate. In all cases, the usefulness of these systems could be increased by adding more alarm levels. In the case of the GTE visibility-alarm system, an ah-clear signal and the ability to download sensor data would also be useful

System Performance

The performance of the test systems was evaluated in terms of functional adequacy, reliability, and cost. Evaluations of these features are summarized here; more detailed evaluations may be found in the subtest reports. Table 3 summarizes findings related to finctional adequacy and reliability.

Table 3. Test System Functional Adequacy and Reliability.

	Functional Adequacy			
System	Design	Performance	Reliability	Remarks
Traffic Census				
GTE External	Yes	Yes	No	
GTE Internal	Yes	Yes	No	
USCL External	Yes	Yes	No	
USCL Internal	Yes	Yes	No	
USCL Infrared	Marginal	No	No	
Incident Detection				
GTE Internal	Yes	No	N/A	
USCL External	Yes	No	Insuff. data	
USCL Infrared	Marginal	No	No	
Weather				
GTE Visibility	Yes	Yes	Yes	Standards inadequate
USCL Visibility	Yes	No data	Insuff. data	
USCL Wind	Yes	Yes	Insuff. data	
CMS Control	No	N/A	N/A	Test canceled
CCTV Surveillance				
USCL B/W'	Yes	Yes	No	
USCL Color	Marginal	Yes	Insuff. data	

Adequacy

Traffic census systems based on loop detectors appeared to function adequately, although at most sites it was not possible to verify the accuracy of the counts due to the lack of comparable data. The infrared-detector-based system did not function adequately, however, in that the detector never produced consistently accurate volume counts or speeds.

The hazardous weather alarm systems functioned satisfactorily to the extent that they did send alarms at times that appeared reasonable. A possible exception is the U. S. Commlink visibility sensor system, which was installed after the fog season and never sent a "real" alarm.

The incident detection systems did not function adequately. The GTE system only sent one alarm over a period of three months The failure in this case was apparently one of system integration, since GTE reported that the counter did produce the correct alarm pulse after it was installed in the field. U S. Commlink incident detection systems sent numerous alarms, but the time patterns of the alarms received appear unreasonable. The loop-detector-based system at U. S. Commlink Site 2 sent alarms which sometimes appeared to be valid, but also sometimes sent alarms in illogical sequences and appeared to understate the degree of congestion believed to exist at the site. By using the CCTV system installed at this site, it was eventually possible to verify that the incident detection unit sometimes failed to transmit alarms when congestion was present. The infrared-detector-based system at U. S. Commlink Site 6 sent alarms in time patterns that appear unreasonable and also failed to provide all the specified alarm levels.

The CCTV systems functioned adequately, except that the lack of PTZ capability and the slow refresh rate limit the usefulness of the color system intended for incident verification. Initial assessments by District 11 TMC personnel were that image quality at two of the sites was inadequate; however, after adjustments to improve image quality, TMC representatives reported that they were pleased with image quality, particularly for the monochrome systems. The TMC representatives judged the color system to be of limited usefulness due to the slow refresh rate. They noted, for instance, that it was difficult to tell whether given vehicles were present in more than one frame.

System Reliability

For the most part, the FOT failed to establish the reliability of the test systems. In a few cases, the systems themselves clearly had reliability problems. More commonly, however, the problem was that it was impossible to evaluate reliability because too little time was available to observe operation of the systems. The GTE visibility alarm systems appeared to function reliability once initial design st aws were corrected. Otherwise, the only installation that functioned reliably over an extended period of time was the traffic census unit at U. S. *Commonlink*` Site 2. The U. S. Commlink Davis weather system functioned reliably once it was reinstalled in April 1996, but was in operation for no more than two months. The U. S. Commlink visibility alarm system was in operation for about two months, but never sent an alarm. All traffic census units other than that at U. S. Commlink Site 2 experienced frequent problems and extended periods of down time. None of the incident detection systems appears to have ever functioned correctly, and the U. S. Commlink systems were in operation only a short period of time. The U. S. Commlink color video system functioned reliably for about six weeks; the monochrome system failed after about three or four weeks, however, and the cause of this failure was never determined.

Even where the problem was related to the performance of the system rather than a lack of time for proper evaluation: evidence of reiability problems should be interpreted with caution. In many ways. the experience of the FOT is not an adequate indication of the potential reliability of the test systems. Many of the problems experienced were due to initial design flaws. In addition some of the down time experienced by the traffic census systems was the result of circumstances peculiar to the FOT, such as the vendors' lack of a resident maintenance staff, the lack of spare components to'replace those that failed, and the extra time required to diagnose the problems of a new system.

cost

Capital costs of deployed call box systems were estimated and compared with those of hardwire telephone systems. Caltrans structured bids for smart call box installations similar to those used in the FOT. The vendors were then asked what they would charge to provide these systems in quantity. For items not supplied by the vendors, costs were derived from standard unit prices used by Caltrans. Based on these, it appears that at most sites all types of smart call box systems have sinificant capital cost advantages over hardwire systems. This cost advantage is due primarily to the extra costs of trenching, wiring, and jacking of conduit under the traveled way that are involved in hardwire systems. Even where external A/C power was required, the cost advantage was substantial, because distances to the nearest access points for the telephone system tended to be greater than those to the power system; however, the greatest cost advantages were for systems that did not require A/C power.

Overall life cycle costs also depend on telephone charges and maintenance costs. Based on rates charged to the voice call box sysrem in the San Diego area, smart: call box systems appear to have a slight advantage in terms of telephone charges. Given the short period of observation, it was not possible to make reasonable estimates of maintenance costs; as an alternative, maximum break-even differences in maintenance costs between smart call box and hardwire systems were calculated based on various assumptions about interest rates and access distances to the regular telephone system. For the access distances typical of the sites used in the FOT, break-even differences in annual maintenance costs range from about $500 per unit up to several thousand dollars per unit, depending on the type of system. This means that the life cycle cost of the smart call box system will be less than that of the hardwire system provided smart call box maintenance costs do not exceed the amounts quoted.

Table 4 summarizes costs. The first column gives estimated total capital cost of providing the equipment used for each type of system for each subtest Where sites were used for more than one subtest, separate cost estimates are given for each subtest. The second column gives estimated costs, exclusive of the cost of providing external power and, where applicable, costs of providing loop detectors. These costs vary a great deal depending on the site, so their inclusion may distort the relative costs of the different systems. The third column gives estimated break-even differences in maintenance costs -- that is, the maximum amount that smart call box maintenance costs can exceed hard wire maintenance costs if smart call boxes are to retain an advantage in life cycle costs.

Table 4. Estimated Costs for Test Systems.

System	Approximate Capital Cost	Capital Cost, Exclusive of A/C Power and Loops	Break-even Difference in Annual Maintenance Cost
Traffic Census			
GTE Systems	$7,000 - $10,000	$3,500 - $4,000	$500 - $1,000
USCL External	$23,000 - $50,000	$6,000 - $10,500	$500 - $1,000
USCL Internal	$7,500	$6,000	$500 - $1,000
USCL Infrared	$76,000	$17,700	$500 - $1,000
Incident Detection			
GTE Systems	$10,000	$3,600	$2,000 - $3,000
USCL External	$50,000	$10,000	$2,000 - $3,000
USCL Infrared	$76,000	$17,700	$500 - $1,000
Weather			
Jaycor Systems	$5,000	$5,000	$7,500
Davis Systems	$3,000	$3,000	$7,500
CCTV Surveillance			
Monochrome	$8,000 - $20,000	$4,000 - $5,000	$1,000
Color	$36,000	$13,500	$1,000

Discussion

In the early stages of the FOT, the major technical problems were expected to involve power supply and the sequencing of transmissions. These certainly proved to be major problems, and the vendors were not able to overcome all the difficulties they encountered. For instance, neither vendor was able to design a system that could provide remote control for a PTZ camera, and neither designed a system that could perform more than two data-collection functions without an external power supply. Where these issues were concerned, however, the test systems tended to function as intended. For example, there were no known instances of a system failure due to an inadequate internal power supply, although there were failures due to disruption of external power at sites that required it. Instead, most of the unexpected problems experienced in the FOT were related to system integration.

The major technical surprise of the FOT was the difficulty of system integration. System integration problems began with the Subphase 0 preliminary communications test and continued throughout the FOT. They seem to have been primarily related to two features:

1. Data collection software supplied by vendors of intelligent external devices (weather sensors, traffic counters, and video compression units) assumed a direct or telephone-modem-based connection to the intelligent device. The call box could be integrated into the system by either modifying the software to communicate with the sensors via a call box, or by having the call box emulate a modem and pass through data without processing or conversion.

2. This software was not adapted to wireless communication. Even when configured as a pass-through system, the wireless communication link characteristics of the call box, . such as high error rate and variable delays, continued to cause problems.

In light of the experiences of the FOT, it appears that system integration problems are likely to recur any time any component of a smart call box system is changed or upgraded, possibly affecting all of the attached devices.

Most system architectures developed by the FOT made little use of the call box microprocessor card. In addition, most sysrems relied on external central computers to provide data reduction and logging capabilities. In light of these facts and the system integration problems, there may have been a fundamental flaw in the smart call box concept. The original concept of smart call box systems was to take advantage of the unused computing power of the call box processor card. But in the systems that were actually developed, the call box processor card contributes little or nothing to the data processing capabilities of the system and adds substantial integration problems.

An alternative would have been to use intelligent single-purpose sensors and connect them to the data processing facilities using cellular modems as the communications link. Like the-call box, the sensors and cellular modems of these systems can be powered by solar units where appropriate. Also, if necessary, they can be housed in existing call box cabinets, since these have already been crash tested and approved for installation in the roadway clear zone. Such systems are Iikely to be cheaper to produce than smart call boxes, as simple cellular modems are cheap compared with existing call boxes, and the system packaging could be done in a much simpler and less costly manner. Consequently, it is likely that several individual systems employing cellular modems could be produced for less than a single smart call box system duplicating their functions.

One way to change this situation would be to have a standard protocol for intelligent sensors or similar devices to communicate with call boxes. The call box sensor communication could be well defined and the processing power of the call box could then possibly be used to analyze data reported by sensors. Since each different type of sensor would report data in the same format and manner, it would be possible to develop software that would run on the call box and perform many of the management functions performed by the central processing and logging system. In addition to the sensor-to call box-protocols, a central-data-processing-to-call-box system would also need to be developed. This would allow users that have specialized processing requirements to either access the data stored on the call box or to directly access their devices.

Efforts are currently underway to develop a National Transportation Communications for ITS Protocol (NTCIP) that will address some of these issues. The purpose of the NTCIP is to be a standard for transmitting data and messages between electronic devices used in ITS. NTCIP is to be a common standard which can be used by all vendors and will provide a common language (messages) and a common syntax (protocols). Of necessity, it is a family of protocols. NTCIP will resolve system integration problems by allowing different manufacturers' components and systems within a common communications infrasturcture. The elements going into the family of protocols are well-known international standards, where they exist. This is important, because using "standards" means that inexpensive hardware and software is already available in the market to implement these protocols. The proposed NTCIP standards are available from the http://fhwatml.com World Wide Web site (2). Information available from this source includes the NTCIP protocols and discussions of work in progress.

The recommended NTCIP physical layer standards are EIA/TIA-232-E, commonly called RS-232, and Bell 202 FSK (frequency shift key) Modem. The data link layer standards are Point to Multi-Point Protocol (PMPP) and Point-to-Point Protocol (PPP); the basis is High Level Data Link Control (HDLC) The network layer is Internet Protocol (IP), or is null (service not provided). The transport layer is User Datagram Protocol (UDP), Transport Control Protocol, or null. The session and presentation layers are null. The application layer is Simple Transportation Management Protocol (STMP) or Simple Network Management Protocol (SNMP) as defined in the Simple Traffic Management Framework (STMF) Telnet and File Transfer Protocol (FTP).

It would be necessary to develop standards for the smart call box higher level interactions. The NTCIP Class B or Class C standards (see http://fhwatml.com/ntcip/library) appear to address these, but do not provide a "reference implementation" or guidelines for developers. A further "application level interface" specification is under development.

Adoption of these protocols for smart call boxes would require a standardization and implementation effort in the intelligent sensor, data communications, and computer software areas that is unlikely to take place unless the potential market for smart call boxes is large enough to allow recovery of the development costs. The technical problems involved in developing the necessary software are surprisingly complex. Most sensor software assumes a direr:. low delay, low error rate connection from the sensors to a data processing package. Some manufacturers have already developed versions of these software packages that function with cellular modems, and while some packages do not work satisfactorily at all rimes with different sets of modems, the standardization of modems and introduction of Cellular Digital Protocol Data (CDPD) modems could reduce these problems in the future. Development of additional protocols, enhancements to software, and other changes to accommodate the use of smart call boxes does not appear viable unless either a large number of sensors will be used for these applications or else users are willing to pay a premium price for these facilities. Because no quantitative market research was performed as a part of the FOT, it is difficult to estimate the potential market for smart call box devices or the sensitivity'of this market to their prices. It is unlikely, however, that the market for smart call boxes will be very large compared with either the overall marker for intelligent sensors or the market for voice call boxes.

In addition, system reliability must be considered. Data gathered during the FOT indicated that major points of failure in the system were the smart call box so&ware and systems that were used to configure the smart call box. System reliability does not appear to be improved by the addition of the call box, and may actually be decreased due to the problems with management of maintenance modes, setting time-of-day clocks, and other issues that were discovered during testing.

Finally, problems of system maintenance and diagnostics were repeatedly evident throughout the FOT. It is clear that built-in test capability to locate system defects is essential if a system is to be used for either incident detection or on-demand functions such as traffic census or CCTV surveillance. The experience of the FOT was that a high level of expertise was needed to determine what element in the system was failing or not performing at an adequate level, and that it took a long time to solve the problems that developed. While problems of this type are to be expected during prototype development and testing, many of them occurred with equipment that had been used in other areas for substantial amounts of time. It appears that integration of new and different types of sensors will require a substantial investment of time and expertise, not only during the initial stages of deployment, but also during system use.

INSTITUTIONAL CONSIDERATIONS

The evaluation of the Smart Call Box FOT also involved an analysis of institutional issues. Issues were identified by reviewing documents related to the FOT and interviewing FOT participants. These issues were analyzed by preparing summaries that described and discussed each issue. listed the organizational participants that raised it, and identified ways to avoid problems associated with the issue and/or actions that need to be taken with regard to it. The details of this process are documented in the subtest report on Institutional Issues.

The most important of these institutional issues have to do with the viability of the smart call box systems and the appropriateness of the designs produced by the FOT. These include:

- ***The compatibility of system designs with transportation system management needs.*** This issue is whether the FOT system designs were based on input from the right people. and whether under-representation of certain groups in the process of developing the system specifications may limit acceptance of the resulting systems. FOT system designs were mostly worked out between the RCT, the Project Manager, and the vendors. with some input from local Caltrans operational personnel and representatives of the sponsoring agencies. It might have been better to have involved a wider group in the development of specifications, and to have had better communication among those who were involved. In particular, it would have been better to have involved operational personnel and representatives of the sponsoring agencies at an earlier stage in the development of test system designs and possibly to have sought input from operational personal from outside the San Diego area.

- ***Procurement concepts for deployment***. Procurement of smart cdl box systems is apt to differ considerably depending on geographical location. In California, there are already extensive voice call box systems, and an institutional system to provide these. This system features county-level funding agencies and a highly privatized system for managing the system and installing and maintaining the call boxes. In the context of the California system, introduction of smart call boxes raises a number of issues related to their ownership and funding, since the agencies providing the voice call boxes are not normally expected to be users of smart cdl box data. Elsewhere, rather different institutional arrangements are likely to result, such as direct ownership and operation by state departments of transportation or similar agencies.

- ***Market size and profitability.*** This is the crucial issue from the point of view of potential vendors of smart call box systems. Lack of quantitative market research was an important omission in the Smart Call Box FOT. As indicated above in the discussion of the technical results of the FOT, a fairly large market may be required in order for potential vendors to recover future development costs, especially in view of the system integration problems encountered in the FOT. It is not clear that a market of this magnitude exists, especially since it appears that a close substitute exists that may avoid some of the technical difficulties experienced in the FOT.

- ***Structure and business practices of the electronics industry***. Several of the private-sector organizations participating in the FOT experienced organizational instability or cash flow problems during the course of the FOT, and in some cases these appear to have had a negative impact on performance. These probiems appear to stem largely from an industry structure that features many small, highly specialized units that are owned by much larger companies that tend to trade them around and, sometimes, to neglect them. Similar situations are likely to arise in the deployment of smart call box systems. Potential problems can be minimized by careful investigation of the qualification of prospective vendors, with particular attention to their resources and the commitment of the parent firm (if any) to the project.

- ***Standards*** Many of the technical problems encountered in the FOT were related to system integration. These might have been less severe had there been standard communications protocols for intelligent sensors and similar devices to communicate to smart call boxes. The NTCIP standards currently under development will address some of the system integration problems encountered in the FOT, but it will still be necessary to develop standards for the smart call box higher level interactions. This issue is closely related to that of the size of the potential market for smart call boxes. Development and adoption of standard communications protocols for smart call boxes is unlikely to take place unless the potential market is large enough to allow vendors to recover the development cost.

A number of other issues related to deployment are discussed in the subtest report on Institutional Issues. In addition, several issues related to the conduct of the FOT were identified. The most important of these were appropriateness the overall organization of the FOT, which featured a private consulting firm acting under contract as Project Manager and an arm-length relationship with the vendors; and the problems experienced with the contracting procedures of the sponsoring agencies. Both these situations led to major delays in completing the FOT, which are described in the "Test Chronology" section of this report.

CONCLUSIONS

This report has presented an overview of the evaluation of the Smart Call Box Field Operational Test. Major conclusions are as follows:

1. For the most part, the performance standards adopted for the FOT provided a reasonable basis for design and evaluation of the test systems; however, in some cases they were probably too restrictive and in other cases turned out to be unrealistic. Also, several important issues were overlooked. The performance standards would probably have provided a better basis for evaluation had a wider range of people been invoived in their development. In particular, participation by representatives of the vendors, the sponsoring agencies, and operational personnel from outside Caltrans District 11 would have been useful Also, their effectiveness as an evaluation tool would have been enhanced by better communication with the vendors during system deveiopment, so that unrealistic or inadequate standards could have been identified and revised..

2. The major technical lesson learned from the FOT was the difficulty of system integration for smart call box systems. This difficulty appears to be related to incompatibilities between the smart call box concept and existing communication system designs for traffic counters, weather sensors, and similar devices.

3. Standard communications protocols for traffic counters, weather sensors, and compressed video systems that accommodate the requirements of wireless communications systems are highly desirable. Given the Tendency for equipment to evolve, such standards may be the only way to ensure that new and different smart call box systems will not need to be invented every time a new model of counter or sensor is introduced. It may be questionable, however, whether the market for smart call box systems is large enough to support development of such a protocol. Any such protocol would form a part of the NTCIP standards currently under development. In order to produce standards specifically adapted to smart call boxes, the current NTCIP effort would need to be extended to include standards for smart call box higher level interactions.

4. Most system architectures developed by the FOT made little use of the call box microprocessor card. This may indicate a fimdamental flaw in the smart call box system design concept, since one major feature of the original concept was to take advantage of the unused computing power of the call box microprocessor. In the systems actually developed, these contributed little or nothing to the data processing capabilities of the system and created substantial integration problems. In retrospect, it would have been interesting to compare the performance of smart call boxes with single-purpose wireless data communication systems without the call box microprocessor.

5. Of the smart call box systems tested, functional adequacy was demonstrated for loop-based traffic census systems, weather alarm systems, and monochrome fixed-field-of-vision CCTV systems intended to verify the condition of changeable message signs or other fixed objects. The performance of the color CCTV system intended for incident verification was marginal. Functional adequacy was not demonstrated for the incident detection systems; the deficiencies of these systems may be comparatively minor, however, and might be corrected by f&her testing prior to deployment. The CMS Control subtest was canceled (in part) because it was discovered that the CMSs used in California are incompatible with smart call box systems.

6. With the exception of the GTE weather alarm systems, reliability was not demonstrated for any of the test systems. In several cases, this conclusion is due to a lack of time to adequately establish system reliability rather than observed unreliable performance. In these cases, no real conclusions can be drawn concerning system reiiability. Test systems in this category include the U. S. Commlink weather alarm systems and the color CCTV system . In other cases, there were numerous problems, some of which may have been due to initial design flaws. Test systems in this category

include the traffic census systems and the monochrome CCTV system. None of the incident detection systems ever functioned correctly, so that no conclusion can be drawn concerning their reliability. With the exception of the GTE weather alarm systems, further testing needs to be conducted prior to deployment to establish system reliability.

7. Based on the test system designs developed as part of this FOT, it appears that smart call box solar power systems can support no more than two data-related functions at one site. This conclusion is based on the performance of U. S. Commlink Site 2, which was equipped with an augmented solar power supply and an external storage battery (that is, the battery was located in an underground vault rather than in the call box cabinet). It is not known whether further improvement of solar power supplies is feasible, since this was not attempted as part of the FOT. Systems involving more than two data-related functions require an external AK power supply, which will add very significantly to the cost at most sites. In terms of their potential utility, logical system packages that meet the constraint of no more than two functions include traffic census-incident detection, weather alarm with sensor-data download capabilities, and monochrome CCTV for verifying the condition of fixed objects such as CMSs.

8. Smart call box systems are cost-effective compared with hardwire telephone systems at most sites, provided their functional adequacy and can be demonstrated and their maintenance costs prove to be reasonable. It is much less likely that smart call box systems will be cost-effective when compared with single-purpose systems consisting of a cellular modem and a traffic counter, weather sensor, video compressor, or similar device.

9. At individual sites, the cost-effectiveness of smart calI box systems as compared with hardwire systems will usually depend on access distances to the conventional telephone system.

10. The potential market for smart call box systems appears to be fairly limited. Prior to further development of smart call box systems, prospective vendors need to conduct market research to determine market size and profitability.

11. A number of institutional issues need to be resolved prior to full-scale deployment of smart call box systems. Agencies considering deployment should prepare detailed deployment plans to resolve such issues as ownership, financing, and provision of maintenance services. Details of such plans will depend heavily on local conditions. In particular, typical deployment plans are likely to differ significantly between California, where there is a well-developed institutional system for providing voice call boxes, and other states.

12. Major institutional problems in the conduct of the FOT itself included inadequate involvement of the sponsoring agencies and potential users of smart call box systems in the development of system designs, an organizational structure that resulted in a

lengthy vendor-selection process, and cumbersome contracting procedures on the part of the sponsoring agencies. These last two problems led to major delays that had a negative outcome on the FOT. A more appropriate basic structure might have been to nave included the vendors and the Project Manager as partners in the original proposal.

In addition to these major conclusions related to the overall results of the FOT, a number of specific conclusions may be drawn concerning the details of the conduct of the FOT and the technical issues involved. Conclusions related to the conduct of the FOT include the following.

1. The evaluation objectives of the FOT were based on the false assumption that system functionality would not be a major problem. In retrospect, the FOT evaiuation should have focused on. system functionality. Evaluation of reliability and maintenance requirements requires a much longer test, and should not have been undertaken until after basic functionality was well-established.

2. In selecting sites for the traffic census and incident detection subtests, more attention should have been paid to the need for verifying traffic conditions. In several cases, no alternative source of automatically-collected traffic data was available in the immediate vicinity. This greatly limited ability to verify traffic counts and the accuracy of the congestion detection algorithms.

3. The evaluation of the hazardous weather reporting subtest was hampered by inability to confirm weather conditions in more than a general way. In the case of the low-visibility alarm systems, it had originally been planned to provide verification by means of a CCTV system. This could have allowed verification of the alarms that were actually received; however, there was never any practical way to eliminate the possibility that sensors were failing to respond to conditions that warranted alarms. As it turned out, even verification of the conditions associated with the alarms was not possible, due to schedule slippage and lack of coordination with the CCTV subtest.

Conclusions related to specific technical issues include the following.

1. The functionality of the infrared-detector-based system used in the traffic census and incident detection subtests was inadequate. The limitation of this system to a single lane per counter and its 24-hour rotating memory feature are major deficiencies. Also, the counts were not accurate on a consistent basis; at best, these detector systems require careful adjustment in order to function correctly. Even if it had functioned adequately, infrared detection technology is expensive, and would rarely be cost-effective when compared to loop-detector-based systems.

2. Among loop-based traffic census and incident-detection systems, those not requiring external power will normally be more cost-effective than those that do, provided reliability and maintenance costs prove to be similar.

3. Where the choice is between use of a stand-alone device with a dedicated cellular phone (whether a smart call box or some other design) and a multipurpose smart call box (that is, one providing both voice and data transmission) the decision may depend on the distance from the data collection devices to the call box. Where an installation is planned for smart call box use from the start, data collection devices such as loop detectors can be installed in close proximity to the call box (or vice versa), but for installations where both call boxes and data collection equipment are already installed and cannot be moved, the distances between the call box and the data collection equipment may be prohibitive.

4. In their current state of development, smart call boxes are probably not capable of handling complicated incident detection algorithms (3-5) that involve combining data from multiple locations. It is not clear that the accuracy of algorithms of this sort is great enough to warrant further development to adapt smart call box systems to them. A possible alternative. which would get around some of the limitations of the speed alarm approach used in the FOT, would be to develop an expert system in which TMC software interprets speed alarms in terms of time of day, location, and possibly data downloaded from nearby locations.

5. In the case of the low-visibility warning system, there may be need for more than isolated warning devices. Rather, what may be required is a carefully designed network of alarm stations which can provide advance warning of the approach of fog.

6. In the selection of weather sensors, there may be a tradeoff between cost and accuracy. This issue was not confronted directly in the FOT because the planned test by U. S. Commlink of a system incorporating a Vaisala weather station was canceled. As originally planned, the U. S. Commlink portion of the subtest would have compared systems incorporating a low-cost weather station (the Davis) with one involving a more expensive but more accurate unit (the Vaisala). Careful consideration needs to be given to the level of accuracy required for traffic-related weather alarms before systems involving high-end weather stations are developed.

7. Real-time video transmissions and PTZ control are both beyond the current capabilities of smart call boxes.

RECOMMENDATIONS

The following recommendations are based on *technical lessons* learned in the course of this FOT and apply to the future development of smart call box and related technologies.

1. No further effort should be expended on the development of smart call box systems for the control of CMSs, as the two technologies appear to be incompatible.

2. Further development of smart call box CCTV systems for general traffic surveillance should be undertaken only if it appears that remote PTZ capability can be achieved and that it is possible to significantly improve the refresh rates achieved in this FOT.

3. Prior to deployment, all systems produced by this FOT should be subjected to additional testing. Specific objectives should be to I) better establish the reliability and maintenance costs of all systems, 2) correct problems with congestion detection algorithms and verify their accuracy, and 3) develop and test response strategies and sensor networks invoiting multiple locations for low-visibility detection systems.

4. Development of the foilowing system enhancements should be pursued: 1) modification of the GTE traffic census systems to provide continuous availability to download data, 2) combination of traffic census and low-speed detection capabilities in a single system, 3) development of multiple alarm levels and all-clear indications for all weather alarm systems, 4) modification of the GTE visibility alarm systems to provide for sensor verification capability and the ability to download sensor data, 5) development of software to record and display weather and congestion alarms at the TMC, and 6) development of a monochrome CCTV system and successful congestion detection systems that do not require external power.

The following recommendations are based on lessons ***learned in the conduct of this*** *FOT* and are intended to apply to future tests of similar technology.In particular, they relate to tests that involve some element of technology development, as opposed to those that merely demonstrate the applicability of an existing technology in a real-world setting.

1. Where possible, tests should focus on solving problems as they are perceived by potential users of the technology being developed, and not on the exploitation of a particular type of technology. In this case, this would haveimplied a focus on developing wireless data collection systems rather than on exploiting existing call box technology.

2. Market research, resulting in quantitative estimates of potential market size, should be included as a formal part of any test that involves development of new technologies or systems,

3. All participants essential to the conduct of the test should be included in the partnership responsible for it and all should be identified in, and contribute to, the initial proposal. This should include the evaluator, any project manager, and any vendors or similar firms essential to the test. It should not be necessary for participants to negotiate contracts among themselves after the test is underway. Inclusion of the evaluator at the initial proposal stage is needed to ensure that test design provides adequately for evaluation. Independence of the evaluation may still be assured by having the evaluator report directly to FHWA.

4. FHWA should decrease its emphasis on formal evaluation and data-management plans. These are less important than having a clear idea from the very beginning of what is to be demonstrated and how.

5. Where development of new technologies or systems is involved, definition of performance standards and specifications should take place early in the process of planning for the test. All test participants (including potential users, vendors, and sponsoring agencies) should be involved in this process. In some cases, it will be desirable to also include potential users from other geographical areas.

6. Contracting procedures used for funding tests should be kept as simple as possible. If separate contracts are to be issued for the test and its evaluation, they should be processed simultaneously.

7. Where systems are intended to serve multiple purposes, and it is necessary to stage the development of the system, each stage or development phase should be organized as a separate test. This is to avoid situations in which schedule slippage in early phases compromises system development and evaluation for later ones. In general, it is best to concentrate on doing one thing at a time. Also, it is wise to start with simple solutions and add enhancements later.

8. In general, evaluation of system functionality and system reliability should be conducted as separate rests. No attempt should be made to evaluate reliability until a system has demonstrated functionality. In assessing reliability and potential maintenance costs, it is also important to make sure that maintenance practices simulate as closely as possible those expected to apply to deployed systems.

REFERENCES

1. Banks, J. H., and P. A. Powell. ***Smart Call Box Field Operational Test Evaluation Subtest Reports.*** PATH Report D96-52. California PATH Program, Richmond, California, 1996.

2. The NTCIP Steering Group. ***National Transportation Communications for ITS Protocol (NTCIP) a Family of Protocols.*** May, 1996. Available at World Wide Web Site http://fhwatml.com.

3. Payne, H. J., and S. C. Tignor. "Freeway Incident Detection Algorithm Based on Decision Trees with States." ***In Transportation Research Record 682, TRB,*** National Research Council, Washington, D. C., 1978, pp. 30-37.

4. Hall, F. L., Y. Shi, and G. Atala. "On-Line Testing of the McMaster Incident Detection Algorithm Under Recurrent Congestion." In ***Transportation Research Record*** 1394, TRB, National Research Council, Washington, D. C., 1993, pp. l-7.

5. Chassiakos, A P. and Y. S. Stephanedes. “Smoothing Algorithms for Incident Detection.” *In Transportation Research Record* 1394, TRB, National Research Council, Washington, D. C., 1993, pp. 8-16.

APPENDIX

VENDOR TEAMS PARTICIPATING IN THE SMART CALL BOX FIELD OPERATIONAL TEST

Team 1

Prime Contractor: GTE Telecommunications Systems, Inc.

Subcontractors:

Jaycor Corporation
TRW Avionics & Surveillance Group
icon networks
Gyyr Inc.

Team 2

Prime **Contractor:** U. S. Commlink

Subcontractors:

Ball Engineering Systems
CCS Planning and Engineering, Inc.
Coastal Environmental Systems
Cohu, Inc.
Davis Instruments
FPL and Associates, Inc.
icon networks
Jaycor Corporation
Lawrence Livermore National Laboratories
Gyyr Inc.
Peek Traffic, Inc.
Schwartz Electra-Optics, Inc.
Vaisala, Inc. ,